Landscape pattern and diversity of natural secondary forests in the eastern mountainous region, northeast China: A case study of Mao'ershan region in Heilongjiang Province

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Abstract: Mao'ershan region is a representative natural secondary forested region in the eastern mountainous region, northeast of China. Under the support of ARC/INFO, the landscape pattern and landscape diversity of Mao'erhshan region were studied by combining the forest type map (1:10 000), which was drawn from the aerial photographs (1999), field investigation and land utilization map (1:10 000). The selected indices included patch number, patch size, patch density index, richness index, dominance index, evenness index and diversity index. The results showed that the landscape dominant forest type in Mao'ershan region was softwood broad-leaved forest. In all landscape types, the average patch area of natural secondary forests was bigger than that of artificial forest. The patch density index of each landscape formed in artificial forest was higher than that of natural secondary forest. The landscape diversity index and landscape evenness index of natural forest were highest, the landscape heterogeneity was also, but the landscape dominance was lower. In natural forest, the control effects of landscape elements on landscape-structure, function and its change were weakened. The artificial forest was on the contrary.

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Introduction

Landscape is a spatial district of higher heterogeneity, in which landscape is constituted on some rules by interacting patches. Landscape pattern analysis is one of the central problems in landscape ecology. The change and development of Landscape pattern (Turner 1987) are the combination of natural, biological and social interaction. The shape, size, amount and spatial combination of landscape patch affect the processes of species distribution, creature movement, runoff, erosion and edge effect (Fu 1995). Thus, the landscape pattern analysis is helpful for studying the interaction between landscape pattern and ecological process.

The research of biodiversity is one of the focuses in the modern ecology research. Many studies have been carried on biodiversity including genetic diversity, species diversity, ecosystem diversity and landscape diversity (Noss 1990; West 1993), but few reports were found on landscape diversity. The landscape diversity reflected the complexity of landscape (Fu 2001). The research on landscape includes the studies of patch number, size and shape, landscape type and distribution, and the connectivity among the patches (Barrett 1994). There are significant relationships between the landscape diversity and landscape heterogeneity. The landscape heterogeneity is one of the important attributes of landscape, and it reflected the variance degree of landscape (Wu *et al.* 1992). The presence of landscape heterogeneity determined the existence of landscape-pattern diversity and patch diversity. The landscape heterogeneity and landscape diversity are the outcome of natural disturbance, human activity and the inherent succession of vegetation (Fu 1995). They had important influences on the transference and transformation of matter, energy and species in landscape. Thus, landscape heterogeneity and diversity become the main components of in research of landscape ecology. At the same time, human activity has importance impact on biodiversity in each level. The landscape fragmentation and habitat destruction have become the main reason in accelerating the species extinct rate (Fu *et al.* 1996). Therefore, the research of landscape diversity and landscape pattern has important meaning in conserving the species diversity.

The landscape spatial pattern is generally measured and analyzed by combing the GIS and the quantified landscape spatial pattern indices. In this study, we analyzed the region landscape diversity by using the landscape diversity indices.

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Through the research on landscape pattern of Mao'ershan region in space, the relationship between landscape pattern and nature, ecological process and social economic activities could be further understood. This is very important in rationally utilizing the land resource, ecologically designing the landscape, laying our soil utilization and controlling the soil erosion.

Study areas and methods

Site description

The research was carried out at the Mao'ershan Experimental Forest Farm of Northeast Forestry University. This area is located between latitude 45°20'-45°25'N and longitude 127°30'-127°34' E, 108 km far away from Harbin, with an average altitude of 300 m and lowest latitude of 160 m. The peak of Mao'ershan mountain is 805 m in elevation. Topography becomes gradually higher from south to north. Average slope grade is 10°-15°. The climate of this area belongs to terrestrial monsoon. Annual average rainfall is 723.8 mm, with about 54% in July and August.

The vegetation type belongs to Changbai Mountain vegetation. The current forest type is secondary forest which succeeded from the zonal climax community broad-leaved Korean pine forest due to human disturbing. The main communities are *Quercus mongolica* Fisch.ex Ledeb forest, *Populus davidiana* forest, *Betula platuphylla* forest, *Juglans mandshurica* forest, *Fraxinus mandshurica* forest, fen and wetland.

The typical mountain earth is dark brown forest soil with rich organic material. There are other types of soil including albidus soil, meadow soil and mire soil (Zhou 1991).

Patch classification

By referring to forest type map (1:10 000) which was drawn by combining aerial photographs of 1999 and ground investigation, topography map of 1993 (1:10 000) and land utilization map of 1999 (1:10 000), the landscape patch distribution plot was drawn with the support of ARC/INFO.

Patch as an element in a landscape, its classification should be first resolved in studying landscape pattern. According to the Mao'ershan land utilizing status and management goals, the 2-grade classification was adopted to truly reflect the landscape characters.

First grade: according to the land utilizing status, patches are classified into forestland and non-forestland. Forestland is the region of vegetation covering degree≥0.2 in arboreal layer. Non-forestland is the region of vegetation covering degree<0.2 in arboreal layer including the land not for forestry objective.

Second grade: based on the first grade, in term of patch appearance, patch occurrence and origination, dominant tree species and land utilizing status, the patches are further classified into Korean pine plantation, larch plantation, *Mongolica* Litv plantation, broad-leaved and conifer mixed plantation, broad-leaved and conifer forest, hardwood broad-leaved forest, softwood broad-leaved forest, nursery, wetland, paddy field, cropland, badland, deforested land and wasteland (hardwood broad-leaved forest and softwood broad-leaved forest are respectively composed by mixed hardwood broad-leaved and softwood broad-leaved tree species without dominant tree species) (Li 2004).

Landscape spatial pattern analysis

Landscape as a natural sustainable unit is an important medium in regional sustainable development, ecological environment and nature conservation projects. The quantifying description and analysis to landscape pattern are basic approaches in revealing the relationship between landscape structure and landscape function, and describing landscape dynamic. Therefore, some landscape structure and spatial pattern analytic methods and the landscape spatial pattern indices were constructed. The landscape spatial pattern analytic methods included the landscape spatial sampling method, landscape patch character method, landscape heterogeneity method, the landscape element spatial correlation analysis, the landscape spatial distribution pattern method, and the landscape dynamic model simulation and prediction method (Guo 2001). The landscape heterogeneity method was adopted to analyze the landscape heterogeneity and landscape diversity in Mao'ershan region.

Landscape element composition

Landscape, as an area, is constituted by reciprocal heterogeneity ecosystems named landscape element, in which landscape element repeatedly appears. The landscape element includes those landscape element types, amount and relatively amount relationship. The landscape element composing is important for the landscape structure and landscape function. The landscape element composing can be reflected by adopting patch amount belonging to the same landscape element type, area and its distribution in a landscape. In a general way, a landscape element with larger area, more patches and extensive distribution range in a landscape may play an important role and has the control-function of landscape structure, landscape function and landscape change in a landscape. Therefore, researching on the landscape element structure, a synthetic index, based on the landscape element area and patch amount, is constructed to analysis a landscape element structure (Guo 2001).

Patch density index

Patch density index is a proportion of patch number to patch area. The ratio of patch amount versus total areas in a study region is all landscapes' patch density index. The ratio of patch amount versus area belonging to the same landscape type is a landscape's patch density index. The landscape patch density reflects the fragmentation degree in a landscape. The bigger the landscape density index, the higher the fragmentation degree and landscape heteroge-

neity (Chen 1996). When the patch density index is calculated according to the landscape element level, the landscape element function and characters in a landscape space, a landscape's fragmentation degree and all landscapes' fragmentation degree in a region can be described by comparatively analysis and the different landscape's disturbance degree can also be distinguished.

Landscape diversity index (*H*)

Landscape diversity index can reflect the landscape element amount and its proportion in a landscape. When a landscape is constituted by a single landscape element, its property is homogenous and its diversity index is 0. When a landscape is constituted by more than 2 landscape elements and these landscape elements have the same proportion in a landscape, their diversity indices are biggest. When those landscape elements have the significantly different proportions, then the landscape diversity degrades. The landscape diversity formula is as follows:

$$H = -\sum_{k=1}^{T} (P_k) \ln(P_k) \quad (1)$$

where, P_k is the proportion of the k type landscape area to landscape total area. T is landscape richness, that is, the amount of landscape genre in study region (Wang 1997).

Dominance index

Dominance index (D) describes the deviation amplitude of landscape diversity to the maximum diversity, or describes the controlled degree of landscape by a few main landscape genres. The bigger the dominance index, the higher the deviation amplitude, that is, the discrepancy of landscape genre proportion in a landscape is higher, or some landscape or a few landscape genres are dominant in a landscape. The dominance index is smaller, and the deviation amplitude is lower. It means that the proportions of landscape genres in a landscape are nearly equal and there are not dominant landscape elements (Wang 1997). The proportions of landscape genres in a landscape are equal, and dominance index is zero.

The dominance index Equation is as follows:

$$D = H_{\max} + \sum_{k=1}^{T} (P_k) \ln(P_k) \quad (2)$$

where, $H_{\max} = \ln(T)$, P_k and T have the same meaning as above. H_{max} is the maximum diversity index in a landscape when all landscape genres have the same proportions in study region (Li 1992; Wu 2001).

Evenness index

Evenness index describes the different landscape genre evenness degree in a landscape. Romme's relatively evenness Equation is as follows:

$$E = (H / H_{\max}) \times 100\% \quad (3)$$

where, E is the evenness index (percentage), H is the landscape diversity index, H_{max} is the probable highest evenness under the given evenness T. H and H_{max} have same formulae as above. P_k and T have the same definition as above.

Evenness describes the same controlled degree of landscape by a few main landscape genres as dominance. Those 2 indices could test each other (Li 1992; Wu 2001).

Richness index

Richness is used to express the amount of landscape element (ecosystem) in a landscape. Usually, richness index can be replaced by relatively richness index. Equation is as follows:

$$R = T / T_{\max} \quad (4)$$

where, R is the relatively richness index, T is richness, T_{max} is the landscape most probable richness (Li 1992; Wu 2001).

Results and analysis

Landscape element composing

According to the above classification criterion, the composing of study area was analyzed at the second grade. With the support of ARC/INFO, by utilizing forest map, remote sense datum, and ground datum, the landscape distribution plot was drawn and linked to database. With the help of program written with AML language, the landscape in Mao'ershan region was classified into 19 types. Each type of landscape's patch amount, individual percentage, area, area percentage, average patch area and patch density index was drawn out with statistical software (Table 1).

Table 1 showed that the area of softwood broad-leaved forest was biggest in all landscapes. Its area percentage was 42.60% in landscape total area; patch number was 635, accounting for 29.8% of the total number of landscape patch, and its average area of patch was 14.043 hm^2, which was higher than the average patch area of forest landscape. In softwood bread-leaved forest grown on the fired secondary nude land or on Korean Pine deforested woodland, its main tree species belong to pioneering specie with strongly germinated ability and situate in dominant status. Mongolian oak forest area was bigger, while its patch number was higher and average patch area was smaller.

In artificial landscapes, larch plantation and Korean pine plantation are main landscapes. As a whole, in all natural secondary forest landscapes, their average patch area was bigger than those of artificial landscapes. Landscape patch density index of plantation was significantly higher than that of natural secondary forests. The reason is that patch area

is smaller and fragmentation degree is higher.

In natural forests, basswood forest is constituted mainly by smaller patch area (average patch area 5.61 hm^2) owing to basswood ecological properties. Thus, the patch density index of basswood forest is biggest (0.18 piece/hm2), and fragmentation degree has the same pattern. The patch density index of softwood broad-leaved forest is smallest (0.071 piece/hm^2), and the distribution pattern was mainly larger patches in softwood broad-leaved forest landscape. The pioneering of softwood broad-leaved community characters is especially dominant. Not only does it easily form smaller scattered-patches, but also its spatial patch expendability is strong. New patch forming and patch expending is simultaneous, and patch expending is the main process. Because of the stable and larger patches forming, and the landscape density index is smaller. The reason of leading to form difference in forest landscape patch density in study area mainly is ecological property of dominant community in forest landscape, besides those, there are other outside factors, such as disturbance and human management. Usually, the stronger human disturbance, the bigger the landscape patch density index, and the landscape fragmentation becomes more serious. Landscape fragmentation brings on smaller landscape patch. The small patch is easy to be managed in artificial landscape; the other way, the forest landscape was constantly divided under these distribution patterns. The larger patches were divided into many smaller patches, and the natural environment integrality was broken, the habitat area in internal forest decreased, and forest corridor was cut off. All these factors can influence species and material circulation.

In our study area, the least landscape is wasteland and suitable for forest. Its average patch area is smallest, but patch density index is highest, and fragmentation is most serious. Therefore, the rationally utilization of forest resources should be done to decrease forest fragmentation.

The analysis of landscape element composition and structure reveals that there are many patches of swampland (75) and wasteland (63) in Mao'ershan plantation, and landscape area of swampland and wasteland were 489.9 hm^2 and 305.9 hm^2 respectively (Table 1). Those swamplands should be conserved. Wetland conservation has impotent effect on biodiversity conservation. At the same time, wasteland rationally utilization should be noticed.

Table 1. Analysis of landscape element composition and structure

Landscape type	Patch number	Individual percentage (%)	Landscape area /hm^2	Area percentage (%)	Average patch area /hm^2	Patch density index (piece/ /hm^2)
Softwood broad-leaved forest	635	0.298122	8917.313	0.426029	14.043	0.0712098
Hardwood broad-leaved forest	152	0.071362	1920.434	0.09175	12.6344	0.0791488
Coniferous and broad-leaved mixed forest	135	0.06338	1378.324	0.06585	10.2098	0.0979451
Mongolian oak forest	261	0.122535	2130.207	0.101772	8.1617	0.1225233
Popular forest	146	0.068545	1750.236	0.083618	11.9879	0.0834173
Birch forest	127	0.059624	1142.125	0.054566	8.9931	0.1111963
Basswood forest	25	0.011737	140.2928	0.006703	5.6117	0.1781987
Korean pine plantation	110	0.051643	924.2517	0.044157	8.4023	0.1190152
Larch plantation	224	0.105164	1041.438	0.049755	4.6493	0.2150872
Scotch pine plantation	96	0.04507	370.0673	0.01768	3.8549	0.2594123
Coniferous mixed plantation	29	0.013615	212.4072	0.010148	7.3244	0.1365302
Deforested woodland	8	0.003756	46.8924	0.00224	5.8616	0.1706033
Wasteland suited for forest	2	0.000939	1.408	6.73E-05	0.704	1.4204978
Barren hill and wasteland	63	0.029577	305.8796	0.014614	4.8552	0.2059634
Swampland;	75	0.035211	489.9021	0.023405	6.532	0.1530918
Nursery	4	0.001878	12.4478	0.000595	3.112	0.321341
Cropland	16	0.007512	91.9815	0.004394	5.7488	0.1739481
Irrigated land	4	0.001878	12.5743	0.000601	3.1436	0.3181082
Else	18	0.008451	43.0468	0.002057	2.3915	0.4181495
Total	2130		20931.23	1		

Landscape diversity index analysis

The landscape diversity index for Mao'ershan region was 2.0084. The landscape diversity index of the natural forests was 1.3941. The landscape heterogeneity was highest and the landscape diversity index of the non-woodland was 0.2094 (Fig. 1 D). The landscape diversity index decreased in the process. The reason is that when landscape is further

classified, the landscape number belonging to the same landscape is less and the landscape diversity index is lower. If diversity were increased to some extent, the stability would be increased. Landscape heterogeneity can improve the landscape resistance to disturbance and dispersion, lessen the disaster menace to landscape stability, and limit the fluctuating range of landscape structure and function in which the landscape element's feedback among the diversified landscape elements can regulate. Therefore, the conservation of landscape diversity of natural forest should be strengthened, and landscape diversity of plantation should be increased. The dominance index for Mao'ershan region was 0.9359. The dominance index of plantation was highest (2.5152) and that of natural forest was lowest (1.9329), (Fig. 1 C). The Table 1 revealed, the proportion of the natural forest to landscape total area is 64.39%, plantation's is 16.36%, and non-woodland's is 19.25%. The Fig. 1 A and C revealed that the bigger the landscape dominance is, the lower the landscape evenness is. The landscape evenness of natural forest was highest (0.3435) and that of plantation was lowest (0.1458). The evenness index for Mao'ershan region is 0.6821. These data showed that the main vegetation type in Mao'ershan region is natural secondary forest with multiple landscape types. The ecosystem distribution for the natural forest was more regular, in which the landscape heterogeneity was higher and there were many landscape types. The plantation area was smaller. The Fig. 1 B showed that the relative richness of non-woodland landscape was highest, and that of plantation was lowest.

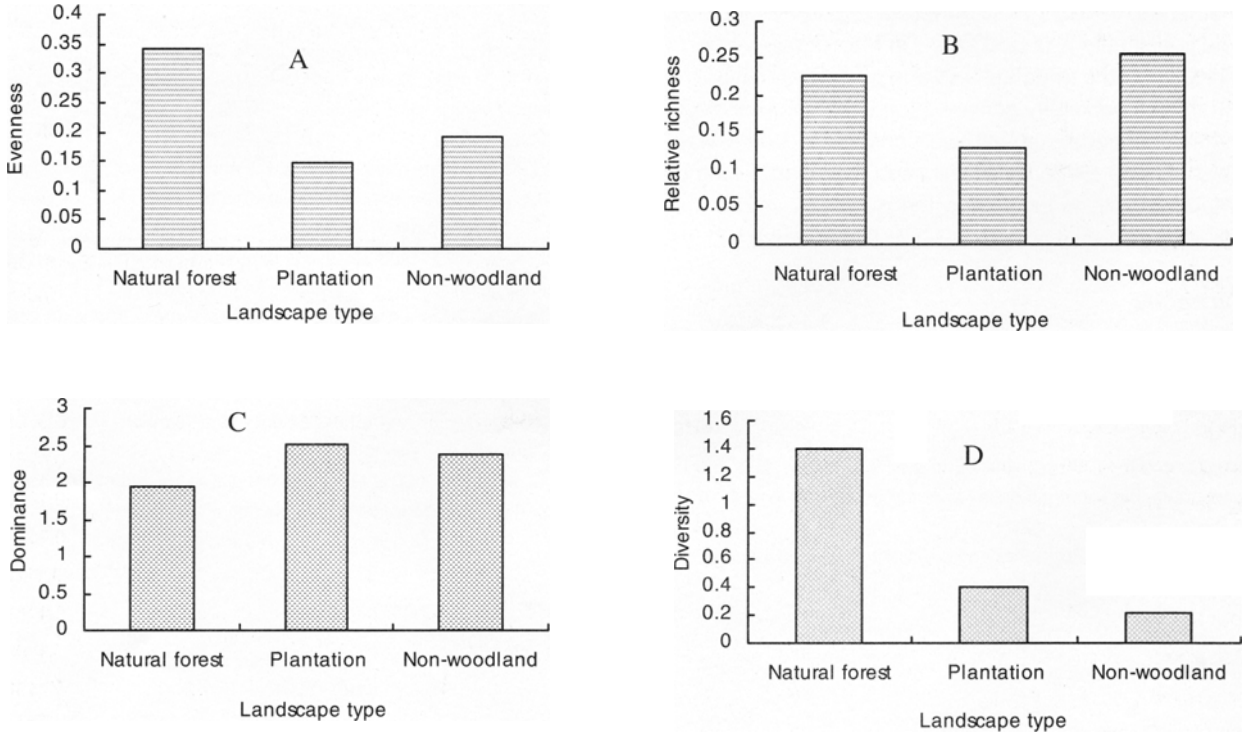

Fig. 1 The evenness, relative richness, dominance and diversity indices for natural forest, plantation and non-woodland landscape types in Mao'ershan region

A----Evenness index; B---Relative richness; C---- dominance index; D----Diversity index

Conclusions

The main landscape forest in Mao'ershan region was softwood broad-leaved forest, which became absolutely dominant by intensely asexual germination. The average area of landscape patch of natural secondary forest was bigger than that of plantation. The patch density of each landscape type in plantation was bigger than that in the natural secondary forest.

Landscape diversity index, landscape evenness, and the landscape heterogeneity of the natural forest were higher, but its landscape dominance was lower and the control effect of each landscape element on whole structure, function and change of landscape was weak, however, the plantation was on the contrary.

Discussion

The landscape element types limited the maximum landscape diversity index. When the landscape element types in a landscape were confined, the more regular the

area distribution for landscape element type was, the higher the landscape diversity index was. There is no correlation between the landscape diversity index and the spatial distribution for landscape element, but there is a correlation between the landscape dominance and the spatial distribution for landscape element. The limited degree of landscape composition and structure by some landscape elements was embodied in the landscape dominance index, and it is a better indicator in evaluating the landscape element position and function in landscape.

Human activity had significant effect on landscape type dominance. Because of the human activity increasing, the landscape dominance of artificial landscape in Mao'ershan region has increased sharply, and the controlling function of landscape element was strengthened. These events showed that the management of landscape by human was strengthened, the economic benefit in region was increased, and habit diversity was decreased in Mao'ershan region.

There are some irrigated land and swampland, which are important in biodiversity conservation in Mao'ershan region, and these resources should be conserved. Some wastelands should be rationally utilized and exploited, which play an important role in increasing the quality of landscape in Mao'ershan region.

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